

## 4. Nitrous Oxide Emissions

### Overview

**U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2000**

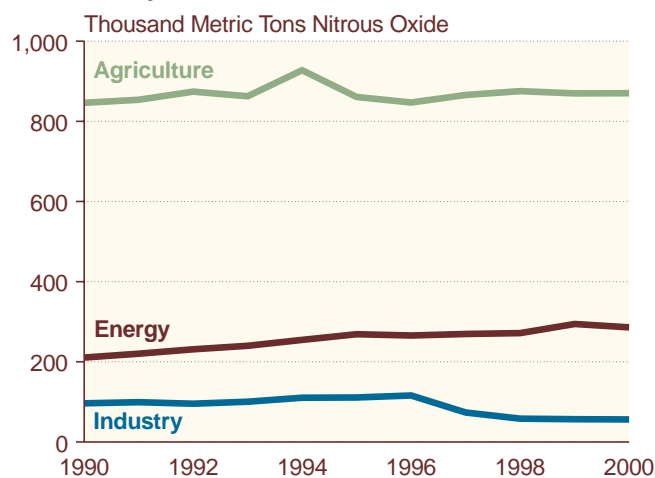
	Nitrous Oxide	Carbon Equivalent
Estimated 2000 Emissions (Thousand Metric Tons)	1,231	99,357
Change Compared to 1999 (Thousand Metric Tons)	-8	-647
Change from 1999 (Percent)	-0.6%	-0.6%
Change Compared to 1990 (Thousand Metric Tons)	62	4,995
Change from 1990 (Percent)	5.3%	5.3%

Estimated U.S. anthropogenic nitrous oxide emissions totaled 1,231 thousand metric tons in 2000, 0.6 percent less than in 1999 and 5.3 percent above 1990 levels (Table 23). Nearly all the increase from 1990 can be attributed to emissions from mobile combustion, which grew by 69 thousand metric tons, between 1990 and 2000, more than offsetting the 40 thousand metric ton decrease from industrial sources (adipic acid and nitric acid production).

The largest component of U.S. anthropogenic nitrous oxide emissions is emissions from agricultural activities. Nitrogen fertilization of agricultural soils represents 73.2 percent of emissions from agricultural activities. Most of the remainder is from the handling of animal waste in managed systems. Small quantities of nitrous oxide are also released from the burning of crop residues. Estimated emissions of nitrous oxide from agricultural sources were 870 thousand metric tons in 2000, 0.1 percent above 1999 levels and 2.9 percent above 1990 levels (Figure 5).

There are large uncertainties connected with the emissions consequences of adding nitrogen to agricultural soils. Models used for estimation are based on limited sources of experimental data.<sup>65</sup> The uncertainty increases when moving from emissions associated with

**Figure 5. U.S. Emissions of Nitrous Oxide by Source, 1990-2000**



Source: Estimates presented in this chapter.

**Principal Sources of U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2000**

Source	Thousand Metric Tons Nitrous Oxide		Percent Change	
	1990	2000	1990- 2000	1999- 2000
Energy Use	210	285	35.8%	-2.9%
Agriculture	846	860	1.6%	-1.1%
Industrial	96	56	-41.7%	-0.9%

animal manure to soil mineralization and atmospheric deposition, where both estimating emissions and partitioning emissions between anthropogenic and biogenic sources become increasingly difficult.

The second-largest source of anthropogenic nitrous oxide emissions is energy consumption, which includes mobile source combustion from passenger cars, buses, motorcycles, and trucks and stationary source combustion from commercial, residential, industrial, and electric power sector energy use. Energy use was responsible for the release of 285 thousand metric tons of nitrous oxide in 2000, 2.9 percent lower than in 1999 but 35.8 percent higher than in 1990.

<sup>65</sup>Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.87-4.100, web site [www.ipcc.ch/pub/guide.htm](http://www.ipcc.ch/pub/guide.htm).

Industrial production of adipic acid and nitric acid, which releases nitrous oxide as a byproduct, accounted for emissions of 56 thousand metric tons of nitrous oxide in 2000, a 41.7-percent decrease from 1990 levels and a 0.9-percent decline from 1999 levels (Table 23). The large decline in emissions from this source since 1990 is a result of the implementation of emissions control technology at three of the four adipic acid plants operating in the United States.

### Energy Use

#### U.S. Nitrous Oxide Emissions from Energy Use, 1990-2000

Estimated 2000 Emissions (Thousand Metric Tons Nitrous Oxide)	285
Change Compared to 1999 (Thousand Metric Tons Nitrous Oxide)	-8
Change from 1999 (Percent)	-2.9%
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	75
Change from 1990 (Percent)	35.8%

The energy use category includes nitrous oxide emissions from both mobile and stationary sources as byproducts of fuel combustion. Estimated 2000 energy-related emissions were 285 thousand metric tons, 23.1 percent of total U.S. anthropogenic nitrous oxide emissions (Table 23). Emissions from energy use are dominated by mobile combustion (82.5 percent of nitrous oxide emissions from energy use in 2000).

### Mobile Combustion

Nitrous oxide emissions from mobile source combustion in 2000 were 235 thousand metric tons, 3.9 percent below 1999 levels (Table 24). In addition to emissions from passenger cars and light-duty trucks, emissions from air, rail, and marine transportation and from farm and construction equipment are also included in the estimates. Motor vehicles are the source of 93.9 percent of nitrous oxide emissions from mobile combustion (Table 24). Emissions grew rapidly between 1990 and 1995 due to increasing motor vehicle use, the shifting composition of the light-duty vehicle fleet toward light trucks, and the gradual replacement of low emitting pre-1983 vehicles in the fleet with higher emitting post-1983 vehicles. The shift to advanced three-way catalytic converters in 1996 through 2000 model year cars has slowed but not abated emissions growth from this source.

Nitrous oxide emissions from motor vehicles are caused primarily by the conversion of nitrogen oxides ( $\text{NO}_x$ ) into nitrous oxide ( $\text{N}_2\text{O}$ ) by vehicle catalytic converters. The normal operating temperature of catalytic converters is high enough to cause the thermal decomposition of nitrous oxide. Consequently, it is probable that nitrous oxide emissions result primarily from "cold starts" of motor vehicles and from catalytic converters that are defective or operating under abnormal conditions. This implies that the primary determinant of the level of emissions is motor vehicle operating conditions; however, different types of catalytic converters appear to differ systematically in their emissions, and emissions probably vary with engine size. Thus, emissions also depend on the "mix" of vehicle age and type on the road.

### Stationary Combustion

During combustion, nitrous oxide is produced as a result of chemical interactions between nitrogen oxides (mostly  $\text{NO}_2$ ) and other combustion products. With most conventional stationary combustion systems, high temperatures destroy almost all nitrous oxide, limiting the quantity that escapes; therefore, emissions from these systems are typically low. In 2000, estimated nitrous oxide emissions from stationary combustion sources were 50 thousand metric tons, 2.2 percent higher than in 1999 and 14.7 percent higher than in 1990 (Table 25). More than three-quarters (82.6 percent) of the emissions increase from this source between 1990 and 2000 can be attributed to coal-fired electricity generation, which grew in response to the growing demand for electricity and lower costs and improved availability at coal-fired power plants. Much of the remainder is attributed to wood combustion in industrial boilers. Coal-fired combustion systems produced 63.6 percent of the 2000 emissions of nitrous oxide from stationary combustion, and the electric power sector accounted for 58.4 percent of all nitrous oxide emissions from stationary combustion sources.

### Agriculture

On a global scale, agricultural practices contribute approximately 70.0 percent of anthropogenic nitrous oxide emissions.<sup>66</sup> Similarly, in the United States, agricultural activities were responsible for 70.7 percent of 2000 nitrous oxide emissions. Nitrogen fertilization of agricultural soils accounted for 73.2 percent of U.S. agricultural emissions of nitrous oxide (Table 23). Nearly all the remaining agricultural emissions can be traced to the management of the solid waste of domesticated animals. The disposal of crop residues by burning also produces

<sup>66</sup>A.R. Mosier, "Nitrous Oxide Emissions from Agricultural Soils," in A.R. van Amstel (ed.), *International IPCC Workshop Proceedings: Methane and Nitrous Oxide, Methods in National Emissions Inventories and Options for Control* (Bilthoven, Netherlands: RIVM, 1993), p. 277.

**U.S. Nitrous Oxide Emissions from Agriculture, 1990-2000**

Estimated 2000 Emissions (Thousand Metric Tons Nitrous Oxide)	870
Change Compared to 1999 (Thousand Metric Tons Nitrous Oxide)	1
Change from 1999 (Percent)	0.1%
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	24
Change from 1990 (Percent)	2.9%

nitrous oxide that is released into the atmosphere; however, the amount is relatively minor, at 2 thousand metric tons or 0.2 percent of total U.S. emissions of nitrous oxide from agricultural sources in 2000. Nitrous oxide emissions from agricultural activities grew by 2.9 percent between 1990 and 2000.

**Nitrogen Fertilization of Agricultural Soils**

Nitrogen uptake and nitrous oxide emissions occur naturally as a result of nitrification and denitrification processes in soil and crops, generally through bacterial action. When nitrogen compounds are added to the soil, bacterial action is stimulated, and emissions generally increase, unless the application precisely matches plant uptake and soil capture.<sup>67</sup> Nitrogen may be added to the soil by synthetic or organic fertilizers, nitrogen-fixing crops, and crop residues. Nitrogen-rich soils, called "histosols," may also stimulate emissions.

Adding excess nitrogen to the soil also enriches ground and surface waters, such as rivers and streams, which generate indirect emissions of nitrous oxide. Additional indirect emissions occur from "atmospheric deposition," in which soils emit other nitrogen compounds that react to form nitrous oxide in the atmosphere. EIA estimates that a total of 637 thousand metric tons of nitrous oxide was released into the atmosphere as a result of direct and indirect emissions associated with fertilization practices in 2000 (Table 26). Estimated emissions increased by 3.5 percent compared with 1990 and increased by 0.2 percent compared with 1999. Nitrous oxide emissions from the application of nitrogen-based fertilizers and biological fixation in crops accounted for 61.2 percent of total nitrous oxide emissions from this source during 2000.

**Crop Residue Burning**

When crop residues are burned, the incomplete combustion of agricultural waste results in the production of

nitrous oxide as well as methane (discussed in Chapter 3). In 2000, estimated emissions of nitrous oxide from crop residue burning were 2 thousand metric tons, up by less than 0.5 thousand metric tons (3.3 percent) from 1999 levels (Table 23). The small increase is mainly attributable to increased corn and soybean production. Emissions from this source remain very small, at 0.2 percent of all U.S. nitrous oxide emissions.

**Solid Waste of Domesticated Animals**

Estimated 2000 nitrous oxide emissions from animal waste management were 231 thousand metric tons, down by 0.3 percent from 1999 levels and 0.9 percent higher than 1990 levels (Table 27), making animal waste the second-largest U.S. agricultural source of nitrous oxide emissions, after nitrogen fertilization of soils. Nitrous oxide emissions from animal waste are dominated by emissions from cattle waste, which account for 93.9 percent of emissions from the solid waste of domesticated animals.

Nitrous oxide is released as part of the microbial denitrification of animal manure. The total volume of nitrous oxide emissions is a function of animal size and manure production, the amount of nitrogen in the animal waste, and the method of managing the animal waste. Waste managed by a solid storage or pasture range method may emit 20 times more nitrous oxide per unit of nitrogen content than does waste managed in anaerobic lagoon and liquid systems. Generally, solid waste from feedlot beef cattle is managed with the solid storage or pasture range method, accounting for the majority of nitrous oxide emissions. Solid waste from swine is generally managed in anaerobic lagoons and other liquid systems. Anaerobic digestion yields methane emissions but only negligible amounts of nitrous oxide. Thus, changes in estimated emissions result primarily from changes in cattle populations. Cattle populations grew during the first half of the decade, leading to higher emissions through 1995, but have since declined slowly, lowering emissions to levels that are close to the 1990 level.

**Waste Management**

Nitrous oxide emissions from waste management are estimated at 19 thousand metric tons for 2000, 1.6 percent of all U.S. anthropogenic nitrous oxide emissions (Table 23). During 2000, emissions from human sewage in wastewater were responsible for 95.7 percent of the estimated emissions from this source, and the remainder was associated with waste combustion. Estimated emissions from waste management grew by 16.7 percent

<sup>67</sup> A.F. Bouwman, "Exchange of Greenhouse Gases Between Terrestrial Ecosystems and the Atmosphere," in A.F. Bouwman (ed.), *Soils and the Greenhouse Effect* (New York, NY: John Wiley and Sons, 1990).

### U.S. Nitrous Oxide Emissions from Waste Management, 1990-2000

Estimated 2000 Emissions (Thousand Metric Tons Nitrous Oxide)	19
Change Compared to 1999 (Thousand Metric Tons Nitrous Oxide)	*
Change from 1999 (Percent)	1.0%
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	3
Change from 1990 (Percent)	16.7%

\*Less than 0.5 thousand metric tons.

between 1990 and 2000 and by 1.0 percent between 1999 and 2000. Because of the lack of reliable data and an effective estimation method, no estimate of emissions from industrial wastewater was calculated, leaving estimated emissions from waste management lower than they otherwise would be had a viable estimation method been available.

### Waste Combustion

In 2000, estimated nitrous oxide emissions from waste combustion were 1 thousand metric tons, 4.1 percent above 1999 levels but 9.8 percent below 1990 levels. While the share of waste burned is estimated to be unchanged between 1999 and 2000, total waste generated increased by 8.4 percent. The total volume of waste generated in the United States increased by 38.3 percent between 1990 and 2000; however, the share of waste burned in 2000 was just 7.5 percent, compared with 11.5 percent in 1990.<sup>68</sup>

### Human Sewage in Wastewater

Nitrous oxide is emitted from wastewater that contains nitrogen-based organic materials, such as those found in human or animal waste. It is produced by two natural processes: nitrification and denitrification. Nitrification, an aerobic process, converts ammonia into nitrate; denitrification, an anaerobic process, converts nitrate to nitrous oxide. Factors that influence the amount of nitrous oxide generated from wastewater include temperature, acidity, biochemical oxygen demand (BOD),<sup>69</sup> and nitrogen concentration.

In 2000, nitrous oxide emissions from wastewater were 19 thousand metric tons, a 0.8-percent increase from 1999 levels and an 18.3-percent increase from the 1990

level (Table 23). Estimates of nitrous oxide emissions from human waste are scaled to population size and per capita protein intake. U.S. population has grown by 10.1 percent since 1990. U.S. per capita protein intake rose steadily between 1990 and 2000, with a brief respite in 1995 and 1996. Today, U.S. per capita protein intake is 7.4 percent above 1990 levels. Data on protein intake are taken from the United Nations Food and Agriculture Organization (FAO).<sup>70</sup>

## Industrial Processes

### U.S. Nitrous Oxide Emissions from Industrial Processes, 1990-2000

Estimated 2000 Emissions (Thousand Metric Tons Nitrous Oxide)	56
Change Compared to 1999 (Thousand Metric Tons Nitrous Oxide)	*
Change from 1999 (Percent)	-0.9%
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	-40
Change from 1990 (Percent)	-41.7%

\*Less than 0.5 thousand metric tons.

Nitrous oxide is emitted as a byproduct of certain chemical production processes. Table 28 provides estimates of emissions from the production of adipic acid and nitric acid, the two principal known sources. Emissions from the combination of these two processes were 56 thousand metric tons in 2000, a decrease of 40 thousand metric tons (41.7 percent) since 1990 and less than 0.5 thousand metric tons (0.9 percent) since 1999.

### Adipic Acid Production

Adipic acid is a fine white powder that is used primarily in the manufacture of nylon fibers and plastics, such as carpet yarn, clothing, and tire cord. Other uses of adipic acid include production of plasticizer for polyvinyl chloride and polyurethane resins, lubricants, insecticides, and dyes.

In the United States, three companies, which operate a total of four plants, manufacture adipic acid by oxidizing a ketone-alcohol mixture with nitric acid. Nitrous oxide is an intrinsic byproduct of this chemical reaction. For every metric ton of adipic acid produced, 0.3 metric ton of nitrous oxide is created.<sup>71</sup> Between 1990 and 1994,

<sup>68</sup>"Nationwide Survey: The State of Garbage In America 1999," *Biocycle* (April 2000). Waste streams were estimated for 2000 by scaling to economic growth, and the share of waste combusted was held constant at the 1999 level.

<sup>69</sup>Biochemical oxygen demand is a measure of the organic content within the wastewater that is subject to decomposition.

<sup>70</sup>Food and Agriculture Organization of the United Nations, statistical databases, web site <http://apps.fao.org>.

<sup>71</sup>M.H. Thieme and W.C. Trogler, "Nylon Production: An Unknown Source of Atmospheric Nitrous Oxide," *Science*, Vol. 251, No. 4996 (February 1991).

emissions from adipic acid manufacture grew by 17.7 percent reaching 67 thousand metric tons (Table 28). After remaining relatively stable in 1995 and 1996, emissions dropped sharply to 12 thousand metric tons in 1998, and they remained at that level in 1999 and 2000.

Through 1996, two of the four plants that manufacture adipic acid controlled emissions by thermally decomposing the nitrous oxide. This technique eliminates 98 percent of potential emissions from the plants.<sup>72</sup> During the first quarter of 1997, a third plant installed emissions controls, increasing the share of adipic acid production employing emissions abatement controls from 74.1 percent in 1996 to 91.6 percent in 1997. With emissions controls in place for the full year, 97.4 percent of emissions from U.S. adipic acid production were controlled in 1998.<sup>73</sup> Estimated emissions of nitrous oxide from uncontrolled adipic acid production decreased from 22 thousand metric tons in 1997 to 7 thousand metric tons in 2000, and 2000 emissions of nitrous oxide from controlled plants remained relatively constant at 5 thousand metric tons. With the share of adipic acid production

employing abatement controls now at nearly 100 percent, future changes in nitrous oxide emissions from this source are expected to result primarily from changes in plant production levels in response to market demand.

## Nitric Acid Production

Nitric acid, a primary ingredient in fertilizers, usually is manufactured by oxidizing ammonia ( $\text{NH}_3$ ) with a platinum catalyst. Nitrous oxide emissions are a direct result of the oxidation. The 7,981 thousand metric tons of nitric acid manufactured in 2000 resulted in estimated emissions of 44 thousand metric tons of nitrous oxide (Table 28). This estimate was 1.7 percent lower than 1999 levels but 10.9 percent higher than 1990 levels. The emissions factor used to estimate nitrous oxide emissions from the production of nitric acid was based on measurements at a single DuPont plant, which indicated an emissions factor of 2 to 9 grams of nitrous oxide emitted per kilogram of nitric acid manufactured, suggesting an uncertainty of plus or minus 75 percent in the emissions estimate.<sup>74</sup>

<sup>72</sup>Radian Corporation, *Nitrous Oxide Emissions From Adipic Acid Manufacturing* (Rochester, NY, January 1992), p. 10.

<sup>73</sup>R.A. Reimer, R.A. Parrett, and C.S. Slaten, "Abatement of  $\text{N}_2\text{O}$  Emissions Produced in Adipic Acid," in *Proceedings of the Fifth International Workshop on Nitrous Oxide Emissions* (Tsukuba, Japan, July 1992).

<sup>74</sup>Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris France, 1997), p 2.18, web site [www.ipcc.ch/pub/guide.htm](http://www.ipcc.ch/pub/guide.htm).

**Table 23. Estimated U.S. Emissions of Nitrous Oxide, 1990-2000**  
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	P2000
<b>Energy Use</b>											
Mobile Sources .....	166	176	186	195	209	222	217	221	223	245	235
Stationary Combustion.....	43	43	43	44	45	45	47	48	48	49	50
<b>Total .....</b>	<b>210</b>	<b>219</b>	<b>230</b>	<b>239</b>	<b>253</b>	<b>268</b>	<b>264</b>	<b>268</b>	<b>270</b>	<b>293</b>	<b>285</b>
<b>Agriculture</b>											
Nitrogen Fertilization of Soils .....	616	621	639	624	686	617	607	628	640	636	637
Crop Residue Burning .....	2	2	2	1	2	2	2	2	2	2	2
Solid Waste of Domesticated Animals ..	229	231	234	237	239	242	238	236	233	232	231
<b>Total .....</b>	<b>846</b>	<b>854</b>	<b>874</b>	<b>862</b>	<b>927</b>	<b>861</b>	<b>847</b>	<b>866</b>	<b>875</b>	<b>870</b>	<b>870</b>
<b>Waste Management</b>											
Waste Combustion.....	1	1	1	1	1	1	1	1	1	1	1
Human Sewage in Wastewater .....	16	16	16	16	17	17	17	17	18	18	19
<b>Total .....</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>18</b>	<b>18</b>	<b>18</b>	<b>18</b>	<b>18</b>	<b>19</b>	<b>19</b>
<b>Industrial Sources .....</b>	<b>96</b>	<b>99</b>	<b>95</b>	<b>100</b>	<b>110</b>	<b>111</b>	<b>116</b>	<b>74</b>	<b>58</b>	<b>57</b>	<b>56</b>
<b>Total .....</b>	<b>1,169</b>	<b>1,189</b>	<b>1,217</b>	<b>1,219</b>	<b>1,309</b>	<b>1,257</b>	<b>1,245</b>	<b>1,226</b>	<b>1,222</b>	<b>1,239</b>	<b>1,231</b>

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 1999*, DOE/EIA-0573(99) (Washington, DC, October 2000). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.81-4.94, web site [www.ipcc.ch/pub/guide.htm](http://www.ipcc.ch/pub/guide.htm); and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1999*, EPA-236-R-01-001 (Washington, DC, April 2001), web site [www.epa.gov/globalwarming/publications/emissions/us2001/index.html](http://www.epa.gov/globalwarming/publications/emissions/us2001/index.html).

**Table 24. U.S. Nitrous Oxide Emissions from Mobile Sources, 1990-2000**  
(Thousand Metric Tons Nitrous Oxide)

Item	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	P2000
<b>Motor Vehicles</b>											
Passenger Cars .....	99	107	115	112	111	108	109	109	110	112	108
Buses .....	*	*	*	*	*	*	*	*	*	*	*
Motorcycles.....	*	*	*	*	*	*	*	*	*	*	*
Light-Duty Trucks .....	49	51	53	64	78	94	88	91	92	111	104
Other Trucks.....	6	6	6	6	7	7	7	8	8	8	8
<b>Total .....</b>	<b>154</b>	<b>164</b>	<b>174</b>	<b>183</b>	<b>196</b>	<b>210</b>	<b>205</b>	<b>208</b>	<b>210</b>	<b>231</b>	<b>221</b>
<b>Other Mobile Sources.....</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>13</b>	<b>12</b>	<b>13</b>	<b>13</b>	<b>14</b>
<b>Total .....</b>	<b>166</b>	<b>176</b>	<b>186</b>	<b>195</b>	<b>209</b>	<b>222</b>	<b>217</b>	<b>221</b>	<b>223</b>	<b>245</b>	<b>235</b>

\*Less than 500 metric tons of nitrous oxide.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 1999*, DOE/EIA-0573(99) (Washington, DC, October 2000). Totals may not equal sum of components due to independent rounding.

Sources: Calculations based on vehicle miles traveled from U.S. Department of Transportation, *Federal Highway Statistics* (various years), Table VM-1. Passenger car and light-duty truck emissions coefficients from U.S. Environmental Protection Agency, Office of Air and Radiation, *Emissions of Nitrous Oxide From Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996*, EPA-420-R-98-009 (Washington DC, August 1998). Emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 1.64-1.68, web site [www.ipcc.ch/pub/guide.htm](http://www.ipcc.ch/pub/guide.htm).

**Table 25. U.S. Nitrous Oxide Emissions from Stationary Combustion Sources, 1990-2000**  
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	P2000
<b>Residential</b>											
Coal . . . . .	*	*	*	*	*	*	*	*	*	*	*
Fuel Oil . . . . .	1	1	1	1	1	1	1	1	1	1	1
Natural Gas . . . . .	*	*	*	*	*	*	1	*	*	*	*
Wood . . . . .	2	2	3	2	2	2	2	2	2	2	2
<b>Commercial</b>											
Coal . . . . .	*	*	*	*	*	*	*	*	*	*	*
Fuel Oil . . . . .	1	1	*	*	*	*	*	*	*	*	*
Natural Gas . . . . .	*	*	*	*	*	*	*	*	*	*	*
Wood . . . . .	*	*	*	*	*	*	*	*	*	*	*
<b>Industrial</b>											
Coal . . . . .	4	4	4	4	4	4	3	3	3	3	3
Fuel Oil . . . . .	5	5	5	5	5	5	5	6	6	6	6
Natural Gas . . . . .	1	1	1	1	1	1	1	1	1	1	1
Wood . . . . .	5	5	5	5	5	6	6	6	6	7	7
<b>Electric Power</b>											
Coal . . . . .	23	23	23	24	24	24	26	27	27	27	28
Fuel Oil . . . . .	1	1	1	1	1	*	*	*	1	1	*
Natural Gas . . . . .	*	*	*	*	*	*	*	*	*	*	*
Wood . . . . .	*	*	*	*	*	*	*	*	*	*	*
<b>Fuel Totals</b>											
Coal . . . . .	27	27	27	28	28	28	29	30	30	31	32
Fuel Oil . . . . .	7	7	7	7	7	7	7	7	7	8	7
Natural Gas . . . . .	2	2	2	2	2	2	2	2	2	2	2
Wood . . . . .	7	7	8	7	8	8	8	8	8	9	9
<b>Total . . . . .</b>	<b>43</b>	<b>43</b>	<b>43</b>	<b>44</b>	<b>45</b>	<b>45</b>	<b>47</b>	<b>48</b>	<b>48</b>	<b>49</b>	<b>50</b>

\*Less than 500 metric tons of nitrous oxide.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 1999*, DOE/EIA-0573(99) (Washington, DC, October 2000). Totals may not equal sum of components due to independent rounding.

Sources: Emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), p. 1.50, web site [www.ipcc.ch/pub/guide.htm](http://www.ipcc.ch/pub/guide.htm). Energy consumption data from Energy Information Administration, *State Energy Data Report 1998*, DOE/EIA-0214(98) (Washington, DC, September 2001); and *Monthly Energy Review*, DOE/EIA-0035(2001/08) (Washington, DC, August 2001).

**Table 26. U.S. Nitrous Oxide Emissions from Nitrogen Fertilization of Agricultural Soils, 1990-2000**  
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	P2000
<b>Direct Emissions</b>											
Nitrogen Fertilizers . . . . .	179	182	183	193	195	173	159	159	161	161	160
Animal Manure . . . . .	6	6	6	6	6	6	6	6	6	6	6
Crop Residues . . . . .	94	91	104	86	112	94	106	114	116	113	116
Soil Mineralization . . . . .	7	7	7	7	7	7	7	7	7	7	7
Biological Fixation in Crops . . .	198	201	203	190	222	210	212	224	232	230	230
<b>Total . . . . .</b>	<b>484</b>	<b>487</b>	<b>504</b>	<b>482</b>	<b>543</b>	<b>490</b>	<b>489</b>	<b>511</b>	<b>522</b>	<b>517</b>	<b>519</b>
<b>Indirect Emissions</b>											
Soil Leaching . . . . .	112	114	115	121	122	109	100	101	101	102	101
Atmospheric Deposition . . . . .	19	20	20	21	21	19	17	17	17	17	17
<b>Total . . . . .</b>	<b>132</b>	<b>134</b>	<b>135</b>	<b>142</b>	<b>143</b>	<b>128</b>	<b>118</b>	<b>118</b>	<b>119</b>	<b>119</b>	<b>114</b>
<b>Total . . . . .</b>	<b>616</b>	<b>621</b>	<b>639</b>	<b>624</b>	<b>686</b>	<b>617</b>	<b>607</b>	<b>628</b>	<b>640</b>	<b>636</b>	<b>637</b>

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 1999*, DOE/EIA-0573(99) (Washington, DC, October 2000). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.89-4.107, web site [www.ipcc.ch/pub/guide.htm](http://www.ipcc.ch/pub/guide.htm). Total nitrogen content of U.S. commercial fertilizer consumption—1988-1994, Tennessee Valley Authority; 1995-1999, Association of American Plant Food Control Officials, *Commercial Fertilizers* (Washington, DC, various years). Manure application based on cattle population data provided by the U.S. Department of Agriculture, National Agricultural Statistics Service, Livestock, Dairy and Poultry Service, web sites [www.usda.gov/nass/pubs/histdata.htm](http://www.usda.gov/nass/pubs/histdata.htm) and [www.nass.usda.gov/ipedb/](http://www.nass.usda.gov/ipedb/). Typical animal sizes from U.S. Environmental Protection Agency, Office of Air and Radiation, *Anthropogenic Methane Emissions in the United States: Estimates for 1990* (Washington, DC, April 1993). Manure production and waste management systems used from L.M. Safley, M.E. Casada et al., *Global Methane Emissions From Livestock and Poultry Manure* (Washington, DC, February 1992), and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1999*, EPA-236-R-01-001 (Washington, DC, April 2001), web site [www.epa.gov/globalwarming/publications/emissions/us2001/index.html](http://www.epa.gov/globalwarming/publications/emissions/us2001/index.html).

**Table 27. U.S. Nitrous Oxide Emissions from Solid Waste of Domesticated Animals, 1990-2000**  
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	P2000
Cattle . . . . .	215	217	219	223	225	228	224	221	218	218	217
Swine . . . . .	5	5	5	5	6	5	5	6	6	6	6
Poultry . . . . .	3	3	3	4	4	4	4	4	4	4	5
Sheep . . . . .	3	3	3	3	3	3	3	2	2	2	2
Goats . . . . .	1	1	1	1	1	1	1	1	1	1	1
Horses . . . . .	1	1	1	1	1	1	1	1	1	1	1
<b>Total . . . . .</b>	<b>229</b>	<b>231</b>	<b>234</b>	<b>237</b>	<b>239</b>	<b>242</b>	<b>238</b>	<b>236</b>	<b>233</b>	<b>232</b>	<b>231</b>

P = preliminary data.

Note: Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Nitrogen content of waste by species, manure management systems, and emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.89-4.107, web site [www.ipcc.ch/pub/guide.htm](http://www.ipcc.ch/pub/guide.htm). Animal populations from U.S. Department of Agriculture, National Agricultural Statistics Service, web sites [www.usda.gov/nass/pubs/histdata.htm](http://www.usda.gov/nass/pubs/histdata.htm) and [www.nass.usda.gov/ipedb/](http://www.nass.usda.gov/ipedb/).

**Table 28. U.S. Nitrous Oxide Emissions from Industrial Processes, 1990-2000**  
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	P2000
<b>Adipic Acid</b>											
Controlled Sources . . . . .	3	4	3	3	4	4	4	5	5	5	5
Uncontrolled Sources . . . . .	54	56	52	56	63	63	66	22	7	7	7
<b>Adipic Acid Subtotal . . . . .</b>	<b>57</b>	<b>60</b>	<b>55</b>	<b>59</b>	<b>67</b>	<b>67</b>	<b>70</b>	<b>27</b>	<b>12</b>	<b>12</b>	<b>12</b>
<b>Nitric Acid. . . . .</b>	<b>40</b>	<b>40</b>	<b>41</b>	<b>41</b>	<b>43</b>	<b>44</b>	<b>46</b>	<b>47</b>	<b>46</b>	<b>45</b>	<b>44</b>
<b>Total Known Industrial Sources. . . .</b>	<b>96</b>	<b>99</b>	<b>95</b>	<b>100</b>	<b>110</b>	<b>111</b>	<b>116</b>	<b>74</b>	<b>58</b>	<b>57</b>	<b>56</b>

P = preliminary data.

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 1999*, DOE/EIA-0573(99) (Washington, DC, October 2000). Totals may not equal sum of components due to independent rounding.

Sources: Data sources and methods documented in Appendix A, "Estimation Methods."

